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Methods of Trench excavation

Civil Engineering

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METHODS OF TRENCH EXCAVATION

BY

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THESIS

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This is to certify that the thesis of HENRY JOHN POPPERFUSS entitled Methods of Trench Excavation is approved by me as meeting this part of the requirements for the degree of Bachelor of Science in Civil Engineering.

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INTRODUCTION

The cost of earthwork forms a considerable item in the construction of small canals, drainage and irrigation ditches, sewers, and the distributing systems of water works. The question of the cost of excavation is an important one both to the engineer who makes the estimate and to the contractor who does the work.

The engineer must have a fairly good understanding of the methods available for doing the work before he can make a reasonably accurate estimate; and before bidding the contractor must study the situation carefully and decide what method of excavation will allow him to make a price that will secure him the contract and also a fair margin of profit for his labor. The magnitude of the work, the size of the trench, the nature of the soil, the location of the job, and the cost of the labor are factors that must be considered in determining the best method to use.

The object of this thesis is to describe the different methods of excavating small canals, irrigation ditches, and trenches for sewers and pipe lines.The relative merits and costs of the different methods will also be discussed.

(A) EXCAVATING BY HAND

Within the last few years digging by hand on work of any considerable size has almost entirely ceased. On small jobs and small-size trenches, digging by hand is more economical than digging by machinery, and experience alone will determine the dividing line. Practical experience has shown that trench excavation by machinery is far more economical than by hand labor, and in order to complete successfully the contractor must have up-to-date equipment.

(a) Nationality of Workmen

There is considerable difference in the value of men of the various races in excavating trenches and the locality in which the work is done determines which race predominates in this kind of work. In Chicago, for example, any sewer or pipe trench work is done mainly by Irishmen with a sprinkling of Italians and Greeks; in Milwaukee Poles are usually employed; in the East Italians largely make up the ditchers; while in the South negroes do most of the trench work. The Poles are the best workers because they are big, strong, and very industrious; on the other hand, the Italians are small of stature, and as a rule are not suited for this kind of work. The Irishman does not make a very good ditcher in a mixed gang, because he thinks himself "better", i.e., more competent and more intelligent, than either of the above mentioned nationalities and consequently does not apply himself assiduously.

A gang of mixed diggers can be made to work efficiently, if a foreman is employed who is always sober and who has the knack to

overcome any difficulties that may arise. In order that the whole work may be carried on successfully, the superintendent must see that the best laborers are employed, and that no "sore heads" and "trouble brewers" are allowed on the job. He must see that all of his men are orderly and that there is no cause for complaint from the people who reside along the line of work.

(b) Method of Doing Work

There are two or three methods of dividing the work of digging a trench between the individual men, but the writer will describe only one, the one which he thinks is the best.

The center line of the trench being given, a strong white line is stretched along the outside boundary of the trench, and, using this as a guide, a few workmen mark the lines by means of their picks. Each man is then given a section from 6 to 20 feet in length, depending on the size of the trench, and is compelled to dig to the required depth. The size of the section should be so chosen as to be completed in a half day or a whole day. The above method is to be employed for all except very wide trenches; but for widths of say 6 feet or more, two men should be given a section in which they work side by side. By assigning a section to each man or to a pair of men, the foreman can determine at any time the progress in each section by simply noticing the depth of each, and when the section is completed the exact yardage of each man is known exactly. Under ordinary conditions a foreman can effectively oversee the work of thirty shovelers, since the men are not distributed over

any considerable length of trench. In loam, or clay, or other soil in which the sides of the trench have but a slight tendency to cave, it is possible to employ as many as thirty men in a trench; but in sandy and gravelly soil a smaller number should be used, as otherwise there will be undesirable caving.

In this method a pacemaker can be used to great advantage, and thereby increase the efficiency of the men. If a good worker is placed in the trench, the men on either side of him will try to keep up with him; and likewise the men next to these will try to keep up with them, and so on; and in this manner fast work is the result. If a ditcher does not keep even with the man next to him, he knows that the foreman will "ball him out"; and fear of this urges him to keep up the pace.

If the bottom of the trench parallels the surface of the street, a stick with the required depth marked upon it is all that is necessary to use to see that the men dig to the required depth. If the trench must be carefully dug to grade, a level and rod must be used.

In a trench up to 9 feet in depth, the earth can be thrown to the surface in one handling. If the material piles up so as to interfere with throwing the earth out of the trench, a man is placed along the side of the excavation who shovels the dirt back. At a depth of 9 feet one surface man is able to take care of three ditchers. For trenches beyond 9 feet in depth, it will be necessary to handle the material two or more times before it finally reaches the surface. A platform is then erected in the trench upon which the ditchers throw the dirt, and from there it is cast upon the surface. One surface man can take care

of two scaffold men, and these in turn can handle four men in the ditch. The platform may be rigged up by placing planks either lengthwise of the ditch, resting upon the cross-braces, or transverse to the trench, resting upon the rangers. In the first case if more than one tier of staging is required, it should be placed alternately upon opposite sides of the trench as illustrated by the end view in Fig. 1; and in the second case if several cross-platforms are to be used, they should be staggered as shown by the side view in Fig. 2.

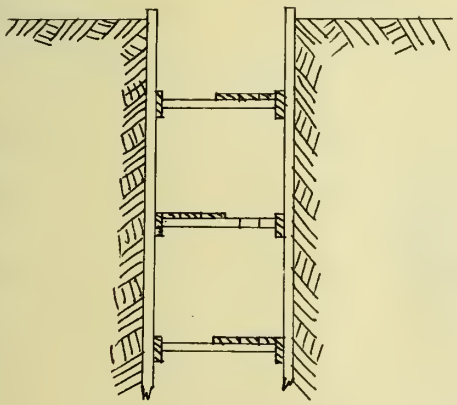


Fig.1.

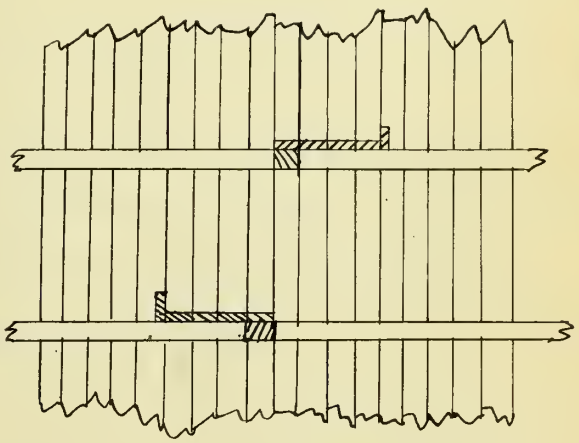


Fig.2.

An old rough-and-ready rule for the hight of scaffolds in trenches was to have them about the hight of a man's eyes, which brought them from 5 to 5 1/2 feet apart. Sometimes contractors had scaffolds an even 6 or 7 feet apart, but today in the larger cities the labor unions require that no lift be more than four feet. The labor unions usually also require one scaffold man for each man shoveling and picking in the bottom.

In case a trench is being dug along a macadam street, often a great deal of time and energy is spent in digging up the pavement by pick and shovel; and on a warm day, with the sun beating down on the white pavement, the removal of the macadam

is very hard on the men. A better method and one very often employed, is to hitch two teams to a contractor's "rooter plow" and tear up the pavement. Usually four men are required to keep the plow in line, as the sudden pull of the horses when ever a a snag is struck sends the plow to one side. A steam roller can be used for pulling the plow, and is usually much more efficient than horses, because it has a steadier and stronger pull. The paving material that is dug up should be carefully shoveled to one side and should not be mixed with the excavated earth because the pavement must be placed back again.

The foreman should see that the picks are always kept sharpened, as this makes easier digging for the men. For ditchers, round pointed shovels are best, while the men on the platform and surface should use square pointed ones.

(c) Cost

At Corning, N.Y., in loamy sand and gravel a water-pipe trench 2 1/2 feet wide, 5 feet deep and 1500 feet long contained 600 cubic yards was excavated in 4 1/2 days by 24 men, or at a rate of 6 cubic yards per man per ten hour day, equivalent to 11 cents a running foot or 25 cents a cubic yeard. At Rochester, N.Y., where the same size trench in the same kind of material was excavated, one man dug 8 cubic yards a day at a cost of 19 cents per cubic yard.

The following data was given by " G. S. W. '88" in the Technic of 1896, the depth of trench being 4 1/2 feet and the wages of labors being 15 cents per hour.

Diameter of pipe, inches	24	18	12-16	10
Cost of excavating, cu. yd.	$0.481	$0.374	$0.313	$0.256

The writer was employed by the Empire Construction Company, of Chicago, last summer in laying 13300 feet of 36-inch cast-iron water pipe for the city of Milwaukee, of which 7000 feet was laid in a trench by hand. The trench was 4 1/2 feet wide and 7 feet deep, and the soil consisted mainly of clay with a small percentage of sand and filled-in ground. The laboring force was made up entirely of Poles who received 17 1/2 cents per hour and worked ten hours per day. A gang of 25 men under one foreman averaged 6 cubic yards per day.

A prominent contractor has calculated the following table based on easy spading earth, and has assumed that the men digging can excavate and throw back 10 cubic yards per day, which is very good work. The wages are $2.00 per day of ten hours. The scaffolds are 4 feet apart; and on the surface is a bankman to throw back.

Depth of trenches	8'	12'	16'	20'
Number of lifts	1-1/2	2-1/2	3-1/2	4-1/2
Number of men	2	3	4	5
Daily average, cu.yds. per man	5.7	4.4	3.3	2.5
Cost per cubic yard	35c	48c	60c	80c
Cost per lineal ft. of trench 27" wide	24c	45c	80c	1.33
100 men would excavate per day, cu. yds.	570	440	330	250
100 men would excavate per day, lineal feet	805	440	247	150

The above costs increase as the ground becomes harder and tougher.

(B) DEVICES FOR EXCAVATING BY POWER

Machines for excavating by power may be divided into three classes: machines designed to excavate ditches: and machines that can be used for either purpose. The first can properly be called trenching machines, and the second with equal propriety may be designated ditching machines; but in the trade and frequently among engineers no distinction is made between a trench and a ditch, and the term trenching machine is applied to what should properly be called a ditching machine and vice versa. The machines in the third class are usually referred to by the name of the machine itself, as steam shovel, orange peel or grab-bucket excavators.

(a) Trenching Machines

There are three trenching machines in common use, namely: (1) Parsons; (2) Buckeye; and (3) Chicago.

(1) The Parsons Trench Excavator

This machine is manufactured by G.W.Parsons Company of Des Moines,Iowa. Their standard machine is capable of digging a trench of any width from 28 to 60 inches,and of any depth to 20 feet, and weighs about 18 tons. The next size machine is capable of excavating trenches of any width from 28 and 78 inches,and of any depth to 20 feet, and weighs approximately 20 tons. The general design and construction of the machine are clearly shown in Fig.3. It is constructed of steel shapes, no wood being used except for the coal and tool boxes. All of the machinery is carried by

Fig.3.

a heavy steel channel frame work, and most of the weight rests on the two large propelling wheels. The excavation is done by an endless chain of flexible steel buckets that travel on a frame. The buckets are 28 inches wide, and have picks on the cutting edge that assist in loosening up the soil. A flexible steel conveyor carries the excavated material and deposits it along the side of the trench. The Parsons machine is self-propelling, moving from one place to another at a rate of two to three miles per hour, and when digging it can be regulated to the desired speed. Fig.4 shows the machine on the car ready for shipment. It can be set up and assembled in a day and a half by the operator and one helper.

Fig.4.

Fig. 5. shows the position of the buckets in the trench ready for excavating. In order to change the size of the trench, it is only necessary to set two small set screws, no additional parts being necessary. The buckets and the framework upon which they travel move backward and forward across the face of the ditch upon a square shaft. The sprocket wheels driven by this shaft upon which the buckets travel are mounted on roller bearings, and this allows the oscillating movement upon the shaft. This movement is positive and requires no attention whatever after being set for the proper width.

The conveyor is constructed entirely of steel and is extensible; and the excavated material can be deposited on one or both sides of the trench at any distance desired. If there is a surplus of material due to swelling and the space is taken by the sewer or water pipe, it can be placed by one of the carriers into wagons and hauled away. The machine can be so regulated as to keep or get rid of the exact amount of earth desired.

The machine is capable of working in any kind of soil and in case large boulders are met with, the power is turned off and the obstructions are removed.

When street car crossings, service pipes, or conduits have to be crossed, the excavator is raised over them and then is fed down again. When a trench is being dug in a town or city, the continual raising and lowering of the digger to pass service pipes loses a great deal of time. To overcome this difficulty, two men are sent ahead to dig down to the pipes, which are generally from three to five feet below surface. These are cut and plugged up and the machine digs through,

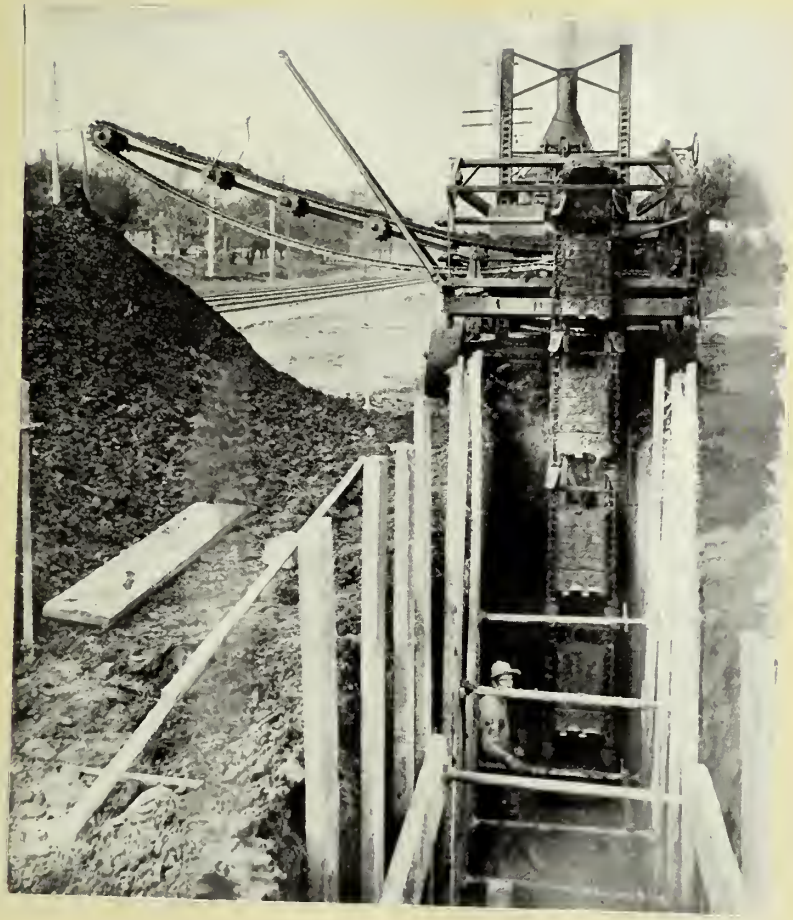


Fig. 5.

after which the pipes are connected.

The weight of the machine is at all times eleven feet in advance of the face of the ditch, and the vibration of the engine in no way disturbs the solidity and compactness of the walls of the newly excavated ditch. The trench can be braced to

within a few feet of the digger, thereby making excavating in loose and wet ground possible.

The Parsons' machine is controlled by one engineer or operator; all the levers necessary for steering, forward traction, fast as well as slow digging, raising or lowering of digger, starting or stopping, and backward speed are within his reach from one platform.

The Parsons' Trench Excavator was used by the Empire Construction Company, of Chicago, in digging a water trench for the city of Milwaukee. This pipe line was laid during the summer of 1909 and the writer was engaged on the work. The trench was 4 feet wide and 7 feet deep, and the excavated material was mainly made up of clay. The average length of trench excavated was 250 feet per day, which practically amounted to 250 cubic yards for a 10- hour day. Time was generally lost by delays caused by boulders in the ditch; by service pipe crossing the line of trench, and by waiting for repairs. The crew consisted of one engineer at $4.00 per day, one fireman at $2.50, and two helpers who put in braces, removed boulders, etc., at $2.00 each. About three-fourths of a ton of coal per day was the average used.

In case hand-digging was to be used, it would require 42 men to dig 250 feet, an average of 6 cubic feet per day, 8 men on the bank to keep the material away from the ditch, 10 men to load wagons, and one foreman. The latter receives $3.00, while the wage of the laborers can be figured at $1.75. Allowing $10.00 a day for interest, depreciation, and repairs on machine, the cost of excavating 250 cubic yards by machine amounts to $26.00, while the same amount of work done by pick and shovel would cost $112.00. With depths exceeding 8 feet the cost of ditch excavating by hand increases very rapidly, whereas the cost

per cubic yard excavated by this machine is the same, whether digging 8 or 20 feet.

The Parsons company rate their machine at a capacity of three-fourths of one cubic yard per minute in ordinary soil. When digging a trench 28 inches wide and 6 feet deep, the machine excavates 0.52 of a cubic yard for each running foot of trench, making 869 lineal feet for each 10 hours of operation. For a trench 60 inches wide and 20 feet deep, 3.70 cubic yards are excavated for each lineal foot of trench, making 121 lineal feet of ditch for a 10-hour day.

(2) BUCKEYE

The Buckeye traction ditcher is a machine that is used a great deal in digging small trenches. This type of machine is manufactured in differet sizes; the smallest one, weighing ten tons, is capable of digging a trench 15 inches wide and 5-1/2 feet deep; the largest one, capable of excavating a ditch 54 inches wide and 12 feet deep, weighs 51 tons.

Fig. 6. shows the construction, as well as the method of operation, of the Buckeye ditcher. The machine consists essentially of a large wheel composed of two rims, between which buckets are mounted. These excavating buckets are provided with teeth or rooters, bolted to the heavy steel bucket tops. Side cutters or knives are bolted to the rims of the excavating wheels and they serve to slice off the sides of the trench, while the rooters loosen up the center.

The excavating wheel has no axle, but is supported by four pairs of rollers inside its periphery. The wheel is supported between I-beams projecting from the rear of the trucks, and the beams can be quickly raised or lowered by the operator, so that the bottom of the wheel can cut to the exact depth and grade desired. The wheel is revolved by means of a pair of driving sprockets, which mesh with the segmental gearing.

The rear end of the frame is supported by a post to the lower end of which is fastened a shoe, which is equipped with a roller to carry the weight. The shoe gives great stability to the wheel and prevents wabbling.

There is a traction attachment so that the whole machine is self-propelling, and moves forward as fast as the

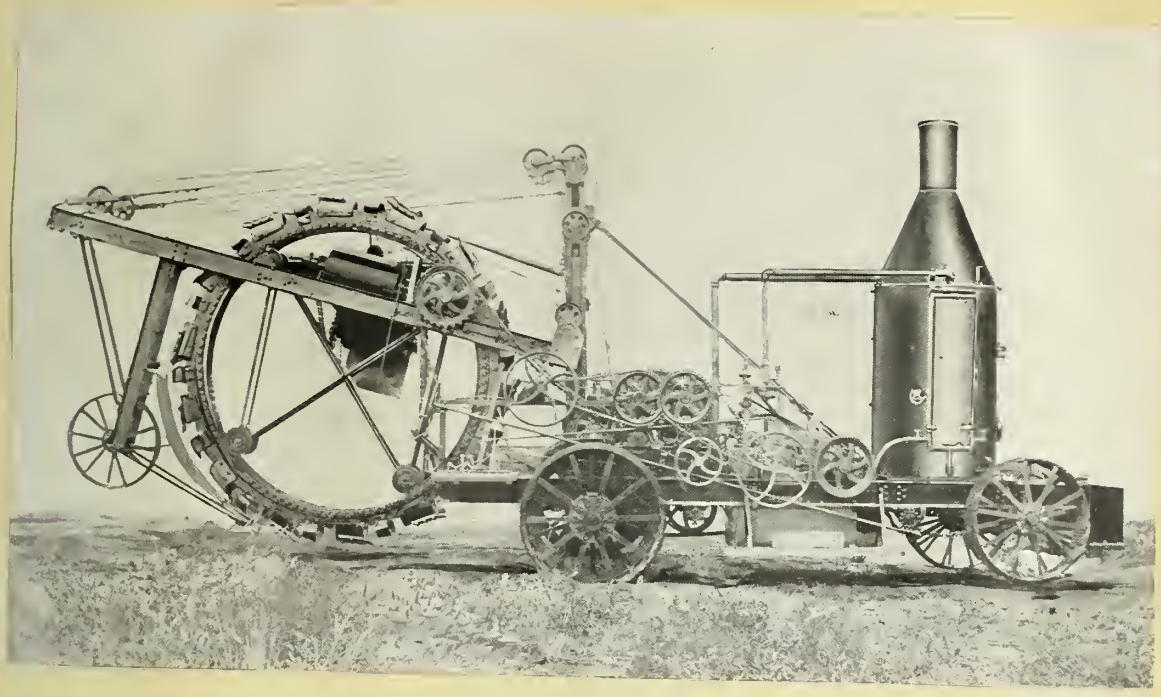


Fig.6.

Fig.7.

digging progresses, the wheel being at the rear of the machine. Thus no weight comes upon the sides of the newly made trench. An endless belt conveyor receives the material discharged from the buckets and carries it off to one side, as is shown in Fig.7.

Any ground that can be loosened with a pick can be excavated by the Buckeye machine. The ditcher will eat through hard pan, or shale, or frozen ground in which profitable picking by hand is impossible. If the cutters strike a boulder too large in diameter to be taken out of the trench, the wheel can be raised out of the trench until the boulder is passed, or a place can be dug by hand for the boulder at the side or it can be taken to the surface, in which case the obstruction is chained fast to the wheel and raised by power.

However there is no danger of breaking the machine when it strikes a boulder, for the booms can be raised when a severe obstruction is met, permitting the cutting teeth to pass over it. At the worst, all that would break would be a cutter bolt or a chainlink either of which is quickly renewed, and at small expense .

In regard to street crossings, service pipes, and conduits, all that was said of the Parson's excavator will apply equally as well to the Buckeye ditcher.

Bracing can be put in as fast as the machine moves ahead, for the trench is cut by the wheel which is at the rear end of the machine.

When working in soft ground the ditcher can be equipped with"apron tractions" as is shown in Fig.8. These consist essentially of a steel frame over which are two endless chains, to which oak planks are bolted. The planks resting on the ground do

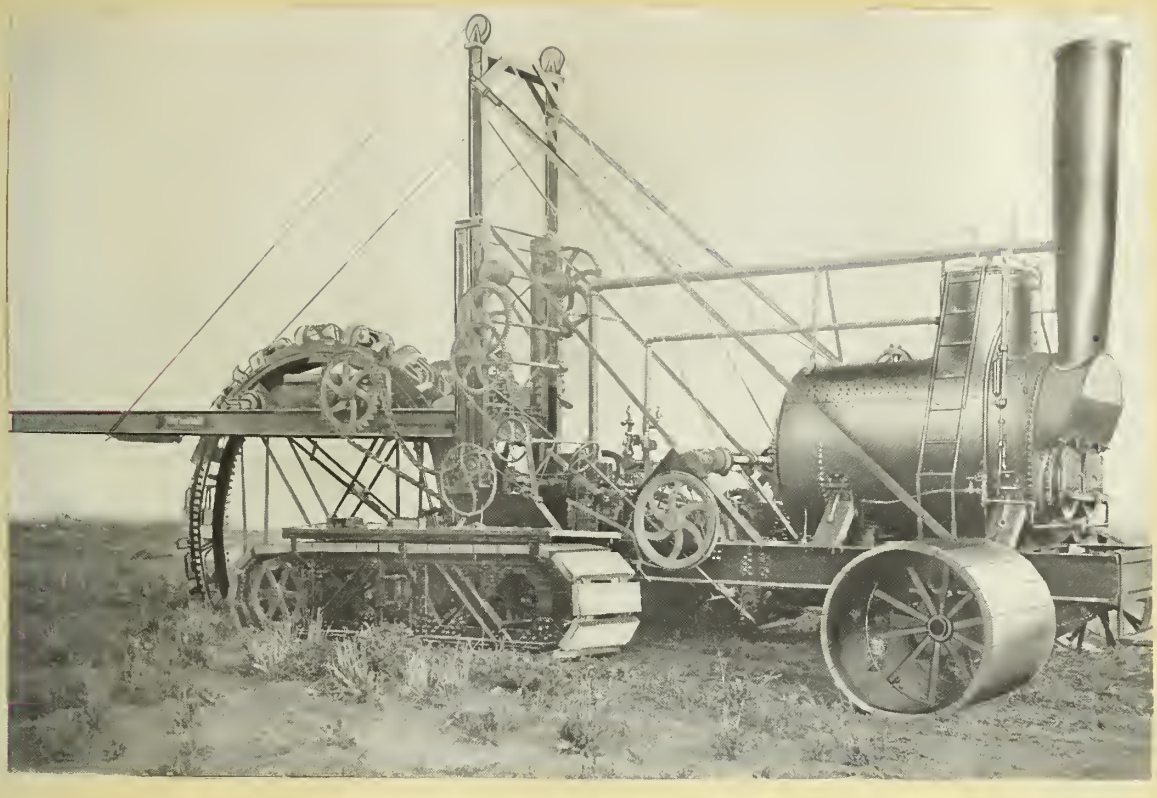


Fig.8.

not move when the machine is under way, simply remaining stationary, as the planks in the rear of the wheel are lifted by the endless chains and carried forward to drop to the ground.

The Empire Construction Co. used a Buckeye machine in digging a trench for a water line in Milwaukee during the summer of 1909. It excavated a trench 28 inches wide by 7 feet deep, the other 20 inches of the 48-inch width being dug by hand. The machine averaged 300 lineal feet, making about 214 cubic yards for ten hours. The material consisted partly of hard clay and partly of filled-in ground, and no water was encountered at all. The crew consisted of one operator at $4.00, one fireman at $2.50, and one helper at $2.00. One ton of coal was generally consumed in a ten-hour run.

The following is the estimate of the cost of operating a Buckeye ditcher for a trench 7 feet deep and 26 inches wide.

	Per day
1 operator	$5.00
1 fireman	$2.50
1 boiler	$2.50
1 laborer, " blocking"	$1.75
1/2 blacksmith, at $2.50	$1.25
1500 lbs. of coal, at $4.00 per ton	$3.00
Total per day	$16.00

With 900 lineal feet of trench for a day's work, the cost of excavating is less than 2 cents per lineal foot, or less than 3-1/2 cents per cubic yard. The charge for interest and depreciation must be taken into consideration. A Buckeye traction ditcher that will dig a trench of this size may be bought for $4,800. Allowing 6 per cent for interest, we have an annual charge of $288. An allowance of $1000 a year of 150 working days for interest and depreciation on a $4,800 traction ditcher would be liberal. This would be equivalent to about $7 per working day, or less than 1-1/2 cents per cubic yard. Adding this 1-1/2 cents to the 3-1/2 cents gives a total of 5 cents per cubic yard for excavating clay of a kind that would cost 25 cents per cubic yard by hand.

The Buckeye company also manufactures a machine for cutting open ditches with sloping banks. Fig. 9. shows the construction and operation of the machine with traction aprons digging a 4-1/2-foot by 3-foot ditch.

The construction of this machine is essentially the same as the Buckeye trench excavator. Instead of having a large wheel with buckets attached, it has a fan-like arrangement of cutting knives with an arrangement for holding the material

Fig. 9.

which is deposited on the side by means of the conveyor.

This type of machine i : quite popular among large land owners throughout the South and West.

(3) CHICAGO

The Chicago Sewer Excavator is a machine that is quite similar in construction and method of operation to the Parsons Trench Excavator. It is sold, and also leased, by the Municipal Engineering and Contracting Company, of Chicago. Fig. 15 shows the general construction of the machine. The excavator consists of an endless chain provided with cutters and scrapers which deliver the earth onto a traveling belt. The conveyor deposits the dirt on one or both sides of the ditch in a pulverized form so that the back-filling is made easy. The earth put back in the ditch settles moreuniformly than where it is scooped out or thrown out by shovels. Fig. 16. shows an end view of the machine and method of operation. The power is furnished by a four wheeled traction engine, and the speed can be regulated to the digging. In going from one job to another the machine is capable of traveling at a rate of 2 miles per hour.

Their largest machine is capable of excavating in depth up to and including 20 feet, with any width from 27 inches up to 60 inches. This is accomplished by changing the buckets.

The company manufactures a back filling conveyor, which is used in connection with their excavator where conditions are favorable. It will deliver to any distance behind the machine from 50 to 75 feet, and is made in two sections of 45 feet each. It is mounted on trucks and operated by its own engine, receiving the steam from the boiler of the excavator. With the back-filling conveyor attached, only sufficient open trench is left in which to carry on the work, thereby almost entirely avoiding open trenches, with their consequent danger to travel.

Fig. 15.

Fig. 16.

This conveyor is practical only where conditions are favorable and where the work proceeds with great regularity; for the reason that the men must keep up with the machine or the machine is held back.

The weight of the small sized machine is 20 tons, while the largest machine weighs 40 tons. The front wheels have a width of 12 inches and the rear wheels 32 inches, while the greatest width from outside to outside of tire is 10 feet 4 inches.

This machine can be equipped with a rolling platform traction to allow working on soft ground .

The excavator can be raised automatically out of the ditch to overcome obstructions, such as large boulders, service pipes, and street crossings.

The Chicago Sewer Excavator is a strong machine as the following experiences show. At Marshfield, Wis., the machine cut through about one mile of logging road where the logs were buried in the ground from 2 to 10 feet, being 6 to 30 inches in diameter. In St. Louis, a 6-inch cast-iron main was plowed through, and in Brooklyn, N. Y., one of the machines took out 26 wagon loads of stone in a distance of 200 feet.

The following information was obtained from H.P.Gillette's" Handbook of Cost Data."

In laying 7 1/2 miles of pipe sewers at Marshfield, Wis., the daily cost of operating a Chicago Sewer Excavator was as follows:

Operator	$ 3.00
Engineer	$ 2.75
Fireman	$ 2.25
Trimmer	$ 2.25
2 Plankmen (bracing)	$ 4.00
Total labor per 10-hour day	$14.25

About 3/4-ton of coal was used daily. In figuring the actual cost per day, the rental, the interest, depreciation, and repairs on the machine must be considered. The trench was 27 inches wide and averaged 7 feet deep. The best day's run was 850 lineal feet of trench, or 500 cubic yards in 10 hours. The average was 400 to 500 lineal feet, or 300 cubic yards per day.

In the summer of 1904, many miles of pipe sewers were built at Wheaton, Ill., by contract. Two Chicago sewer excavators were used, cutting a trench 2-1/2 feet wide, and from 7 to 18 feet deep.

One machine would excavate 750 lineal feet of trench 7 feet deep through hard clay mixed with small stones, in a 10-hour day. In cutting trenches 15 to 18 feet, a machine would average 150 to 200 lineal feet per day, depending upon how much bracing was necessary.

(b) Ditching Machines

Practically the only machine of this type in use in this country is the Austin machine.

(1) Austin

The Austin drainage excavator is used quite extensively for digging drainage and irrigation ditches, and a modification is used in building levees. These machines are manufactured by the F.C. Austin Company of Chicago.

Fig. 10 shows the construction and operation of the Austin drainage excavator, Type 4. It is constructed of standard shapes and is supported on a track resting on the surface of the ground, one rail being placed on each side of the ditch. The distance between track rails ranges from 28 to 40 feet, depending on the size of machine; thus mounted it can easily be propelled forward or backward at the will of the operator.

The excavating buckets, which hold about 1 1/3 cubic yards, travel in guideways transversely of the ditch and shave a thin slice down one side, across the bottom and up the opposite side. The frame carrying the buckets is lowered as the ditch increases in depth so that the banks and bottom can be cut to the required cross-section.

The excavator can be operated to make successive cuts the full depth of the ditch or to travel back and forth along a stretch of about 100 feet, making a series of continuous shallow cuts until the grade is reached. The machine can be adjusted to dig any ditch from 30 feet wide (base) and 1 foot deep to 8 feet wide (base) and 12 feet deep.

The waste banks can be constructed at a distance from the

ditch and they may be made continuous to serve as dykes, or earth can be delivered to either side, as is shown in Fig.11. This illustration shows also the rear view of the excavator in

Fig. 10

Fig. 11.

operation, the good slope of the banks, the continous waste bank, and width of berm.

The machine travels along the work by its own power, and it is capable of going from one job to another without dismantling at the rate of a mile a day. The motive power is about 40 H. P. and about one ton of coal is required to operate this machine for 10 hours. As can be seen from the illustrations, this machine digs a trench all parts of whose banks and bottom are true to grade and equally firm, and therefore offer no resistance to water; whereas the ditch dug by a dipper dredge offers more resistance, and the seepage of water is greater. The Austin machine can cut a ditch true to grade with the banks sloped to any desired angle. By the dipper dredge method the ditch must be dug one ot two feet deeper and several feet wider than specified to provide for sloping banks, (as the necessity of these is almost self-evident.). Solid rock is about the only material which will stand up permanently if excavated with vertical sides. A comparison of irrigation ditches dug by the Austin excavator and by a dipper dredge is shown in Figures 12 and 13 respectively.

In draining large areas, work may be begun at the mouth of the ditch by the Austin machine, thus draining the adjoining lands as the ditch progresses and making them available for agricultural purposes without much loss of time.

The entire working force required to handle a machine of this kind consists of an engineer, a fireman, and two men to handle the track.

In satisfactory soil the Austin Company guarantees their machines to excavate from 50 to 75 cubic yards per hour.

Fig. 12.

Fig. 13.

Two of these machines were used by the T. A. Gillespie Company, of New York City, in constructing a 72-inch steel pipe line for the Borough of Brooklyn. A description of the work is contained in the Engineering Record, September 18, 1909. The first of the machines cut to half the depth, and the other completed the trench, both of them cutting side slopes of 1 to 1.

As much as 3500 feet were dug per week, the progress of course being entirely dependent upon the depth of cut, the valleys to be crossed, and the character of the digging. The excavators, according to the superintendent in charge of the work, handled about 2000 cubic yards each in 24 hours, cutting to a maximum depth of about 11 feet below the natural ground surface.

About 30 men were attached to each excavator, being employed in laying rails ahead of the machine, in operating it, and in hauling back the spoil to the outside of the dump from the point where it was deposited by the excavator bucket.

Fig. 14. shows the "Type C " machine and the final cut on the Los Angeles Aqueduct, the longest in the world, and costing $24, 500,000. This machine digs a trench with vertical sides and from the illustration it can be seen that the conduit is ready for concrete without hand finishing. The rolling platform traction was used on this machine, thus dispensing with two track handlers.

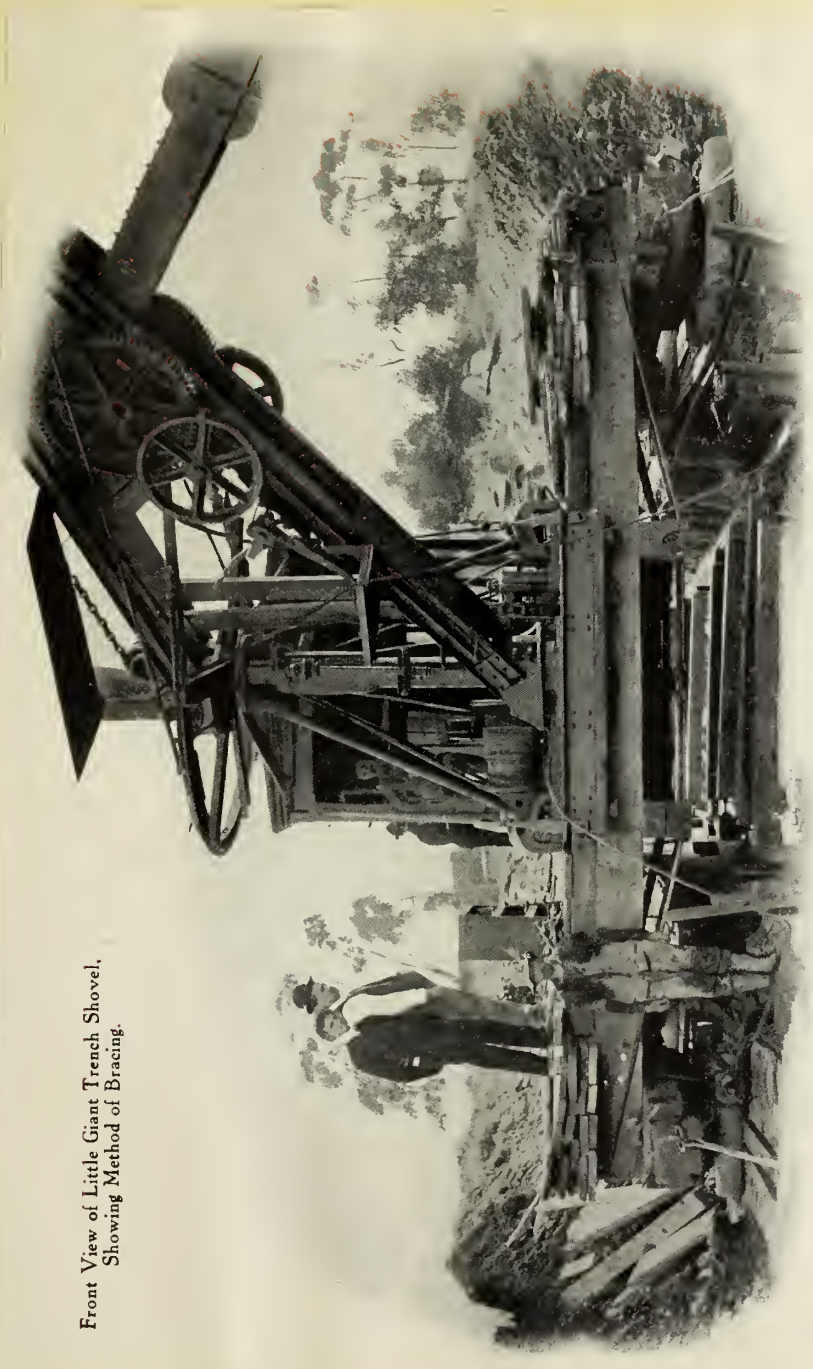
Fig. 14.

(b) STEAM SHOVEL

Steam shovels are used quite extensively in digging drainage ditches, but in excavating sewer and water line trenches their use is somewhat limited. When the comditions are favorable, however, this method will be found in every way practicable and desirable. Where the ground is solid, and where there is ample space for the machine to work in and to deposit the excavated material, this method may be used to advantage. It would not be advisable, however, to use a steam shovel for a trench less than 5 feet wide or over 15 feet wide and 20 feet deep.

The machines vary in weight from 32 to 75 tons, and having a dipper of from 1 to 2 cubic yards capacity. A dipper somewhat smaller than ordinarily employed and of special design is used for trench work. It is usually made round and carries five teeth, so as to cut the edges of the trench. The bail is fastened to the inside of the dipper, so as not to interfere with the teeth cutting on the inside of the trench. Material can be dumped from 14 to 24 feet away from the center line of the trench, according to the size of the shovel used.

Fig. 17. shows the usual method of mounting a steam shovel on a timber frame for trench work. The machine shown in the illustration is a Little Giant trench shovel, weighing 30 tons and using a dipper of one cubic yard capacity. The machine is mounted on heavy timber framing composed of four oak timbers running lengthwise and four running crosswise with the shovel. A steel truss-rod is fitted over the ends of each cross timber. These pass under the two inside timbers that run lengthwise and



Front View of Little Giant Trench Shovel, Showing Method of Bracing.

Fig. 17.

are held together in the center with a turnbuckle so that they can be tightened when necessary. The truss holds the timbers firmly in place, forming a solid foundation for the shovel.

To the two outside timbers are bolted skids, which operate over rollers that run along each side of the trench on planks. Fig. 18. shows a side view of the steam shovel and method of mounting.

The shovel is propelled by means of a cable attached to the forward end of the two outside timbers and rigged to a"dead man" ahead of the shovel. The back filling can be done with the same shovel by mounting it on traction wheels and using a short dipper handle.

Fig. 19. shows another method of mounting the steam shovel. The machine is a new revolving shovel equipped with a special boom, dipper handle, and dipper. The machine is mounted on traction wheels that run on heavy planks, the entire weight being supported by heavy timbers that span the trench. The machine propels itself. It likewise handles the supporting timbers from rear to front.

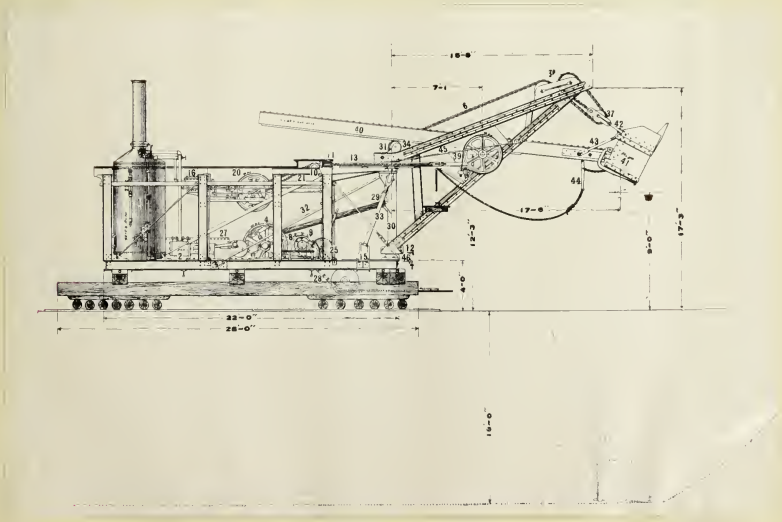


Fig. 18.

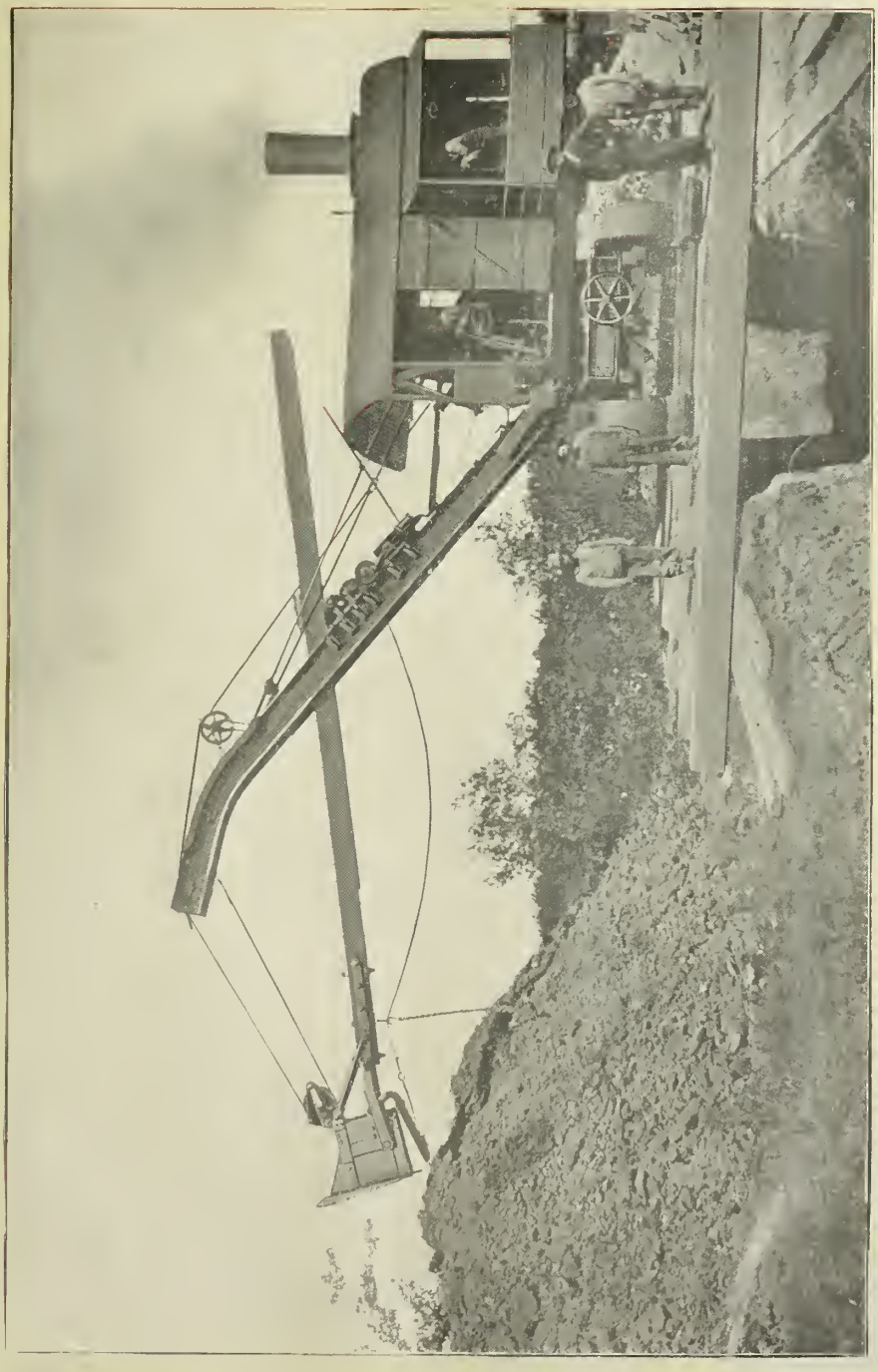


Fig. 19 .

Fig. 20. shows the Thew steam shovel in shallow cut irrigation ditch work. As can be seen from the illustration, the horizontal crowding motion of the dipper permits the filling of the latter in shallow cuts and the cleaning of the floor ahead for the reception of the track.

The full circle swing is advantageons for handling track sections for car wheel machines or plank platform traction mountings from rear to front of shovel. This method of operation reduces the number of laborers required about the shovel to a minimum, and is particularly desirable where the width of ditches is so narrow as to make inconvenient the shifting of track by hand method.

In case a revolving steam shovel could not be used because of the clearance required by the machine in revolving, a machine with the boom pivoted to a turntable could be used.

Fig. 20.

Fig. 21. shows a Little Giant shovel digging a sewer trench 20 feet deep in St. Louis, Mo. It weighs 32 tons and has a dipper handle 25 feet long with a bucket of one cubic yard capacity. The pipe line which was 20000 feet long and 7 feet in diameter was built by the Parker- Washington Co. of Chicago, Ill.

Nash and Dowdle, of Chicago, employed a Vulcan and a Bucyrus steam shovel in excavating for the main sewer under the yards of the Chicago Transfer and Clearing Co. These machines were mounted in the same way as the one described. The excavation comprised 2 feet of black soil, followed by 12 to 20 feet of blue and chocolate clay, with more or less water seams.

The following table shows the character and the progress of the work done.

Length of trench in ft.	2,913	3,099	1,273	5,090
Width of " " " max.	10	7	7	6
Depth of " " " max.	10	15	15.5	13.8
" of " " " min.	10	6	14.5	9.6
Make of steam shovel	Vulcan	Vulcan	Bucyrus	Bucyrus
Capacity of bucket, cu.yds.	1-1/2	1-1/2	3/4	3/4
Length of dipper arm, ft.	36	36	36	36
Ave. progress per day, ft.	69.8	98	85	--
Ave. excavation per day, cu.yds # 10- hour day.	492	245	330	293

A 65-ton steam shovel with 1-1/4-yard dipper was used in excavating a trench for a 5-foot concrete sewer in Chicago. A trench 7 feet wide was excavated by the shovel with an average depth of 14 feet, the average work done per day being 210 lineal feet of sewer, or about 735 cubic yards of excavation .

feet of sewer or about

Every half-hour the shovel would move ahead about 14 feet, requiring about ten minutes in moving for each twenty minutes of work in trenching.

The daily cost of operation was about $34.50 for the shovel service, including engineer, craneman, and fireman, together with six laborers and the cost of three tons of coal, this giving a net cost per foot of about 16 cents for the 210 lineal feet of excavation completed per day of eight hours. This excludes interest and depreciation on equipment, superintendence, and losses on account of weather and accidents.

A steam shovel of the regular Little Giant trench type, fitted with a special high crane to admit of an extra high dump, was used in the construction of a sewer system in Louisville, Ky., costing $4,000 000. The sewer is five miles long, and the excavated trench was 35 feet deep and 20 feet wide, the material consisting mainly of stiff clay. The first 12 feet was taken out by steam shovel and loaded on wagons. This material was wasted because of the fact that it was not needed for the back fill, as the sewer was of such size that the material from the remaining 23 feet of trench was quite sufficient for that purpose. The remaining 23 feet of trench was excavated by hand and loaded into buckets that were hoisted and carried away on trestles. A special sheet-piling pile driver followed the shovel, and drove steel sheet-piling at each side of the trench to the depth of 35 feet. This was braced, and it held the banks up during the excavation of the remaining 23 feet and the construction of the sewer proper. The driving of the piling after the first 12 feet had been taken out resulted in a considerable saving to the contractors, due to the decreased depth of stiff clay that had to be driven through.

The system ended in a tunnel, 17 feet in diameter and about 50 feet below the surface of the ground at a point where it empties into the Ohio river.

LITTLE GIANT TRENCH SHOVEL DIGGING A SEWER TRENCH 20 FEET DEEP IN ST. LOUIS, MO. THE PIPE LINE WAS 20,000 FEET LONG AND 7 FEET IN DIAMETER. PARKER-WASHINGTON CO., CONTRACTORS.

Fig. 21.

(c) ORANGE PEEL OR CLAM SHELL

Orange peel and clam shell buckets are not used to a very great extent in trench excavation. The former is the more popular because of its greater closing and digging power; and because of its numerous blades there is less resistance in digging. For handling loose material, such as sand, coal, and broken stone, the clam shell bucket is undoubtedly more efficient.

The use of an orange peel bucket in trench excavation, of course, depends upon conditions and upon the character of the material to be dug.

Figs. 22 and 23 show the general construction of a Hayward multi-power orange peel bucket. This type is used quite extensively for digging clay and other hard material. It is constructed of four curved triangular blades, made of flange steel, and when closed form a tight semi- spherical bowl, which holds the excavated material. The upper center is fitted with an oscillating head which carries the deflecting sheave. The power wheel is fitted to a steel shaft which extends on each side to receive the cams to which are attached the side chains. The power wheel frame is made of plates and is so designed that it acts as a stop, which prevents the blades from overlapping when the bucket is closed. It is fitted with outside cast-steel points, which give the blades a smooth surface on the inside, thereby preventing sticky material from clinging to the blades when the bucket is discharging its load.

These buckets vary in capacity from 3/4 of a cubic yard to 2-1/2 cubic yards, and in weight from 4200 to 10500 pounds.

Fig 22.

Fig. 23.

Figs. 24 and 25 show the construction of a class "E" Hayward clam shell bucket that is used for trench excavating purposes. It is made of two flange steel shells or bowls on each side of which are riveted vertical arms, and their upper ends are connected to the main shaft on which the power wheel for closing the bucket is located. The outer ends of the bowls are fitted with lugs which receive vertical connecting rods, which are pivoted at their upper ends to the upper center block or casting.

The upper center casting is so constructed that the four connecting rods work from one center, allowing the casting to oscillate and the bucket to hang centrally under all conditions. The plate-steel shoes that form the cutting edge extend to the top of the bowl.

These buckets vary in capacity from 1/2 of a cubic yard to 5 cubic yards, and in weight from 2100 to 11000 pounds.

An orange peel bucket can be used in connection with a locomotive crane or traveling derrick for digging trenches. Fig. 26 illustrates a locomotive crane with an orange peel bucket digging a sewer trench. The car runs along on rails that are laid along side of the ditch. If there is ample space the material can be deposited beside the tracks, or on the other side of the trench, and after a section of the sewer is completed the buckets can be used for back filling the trench.

The sides of the ditch must be braced firmly to prevent the weight of the crane from caving in the walls.

Fig. 24.

Fig. 25.

Fig. 26.

Fig. 27 shows the use of an orange peel bucket by the United States Government in constructing sewers at Colon, before work was commenced on the Panama Canal a few years ago. The excavator consisted essentially of an orange peel bucket suspended from the boom of a derrick. The whole contrivance moved along on rollers in advanwe of the ditch, and was operated by a contractor's engine.

No data were found in regards to the efficiency of an orange peel or a clam shell bucket in trench excavation.

Fig. 27.

(1) CARSON

A type of machine used a great deal in trench excavation, and especially is this true in sewer work, is the one in which a bucket travels on a trolley suspended from a rigid track supported by trestle bents.

The Carson hoister and conveyor is of this type and its general construction is shown in Fig. 28. The machine consists of a series of A- bents which straddle the trench and are connected at the top by an I- beam section. This serves as a trackway, and is composed of two 12-inch channels, weighing 20 pounds per foot, riveted together back to back; and upon the lower flange of the beam runs the traveler, or trolley, which carries the buckets. Fig. 29 shows a view of the carriage mechanism of the Carson machine and also the hoisting engine. The legs of the A-bents are provided with wheels at the bottom riding on a track straddling the trench, and the whole trestle can be moved forward in 5 to 10 minutes without taking the trestle apart.

These A-bents are of 6"by 8"spruce, 20 feet high and have a spread of 18 feet at the bottom. A hoisting engine at one end of the track, with a return pulley at the other end, supplies power by which the buckets attached to the travelers are raised and lowered, and also moved forward and backward. As a rule 12 buckets of 1/5 cubic yard capacity each are used in the operation of this machine. Six buckets are left in the trench to be filled while the other 6 are carried back and dumped. The method of operating this machine consists in loading the buckets by hand, raising them from the bottom of the ditch and carrying

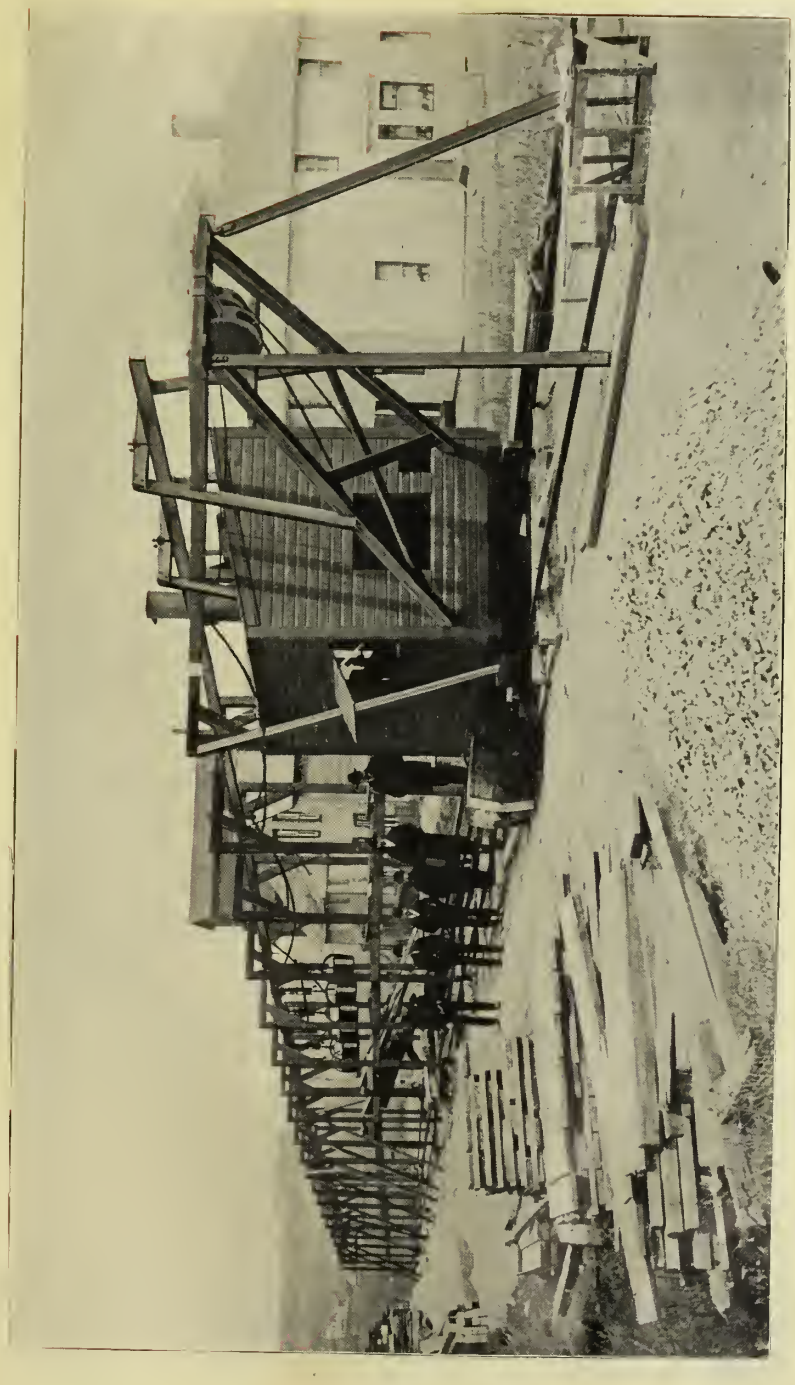


Fig. 28.

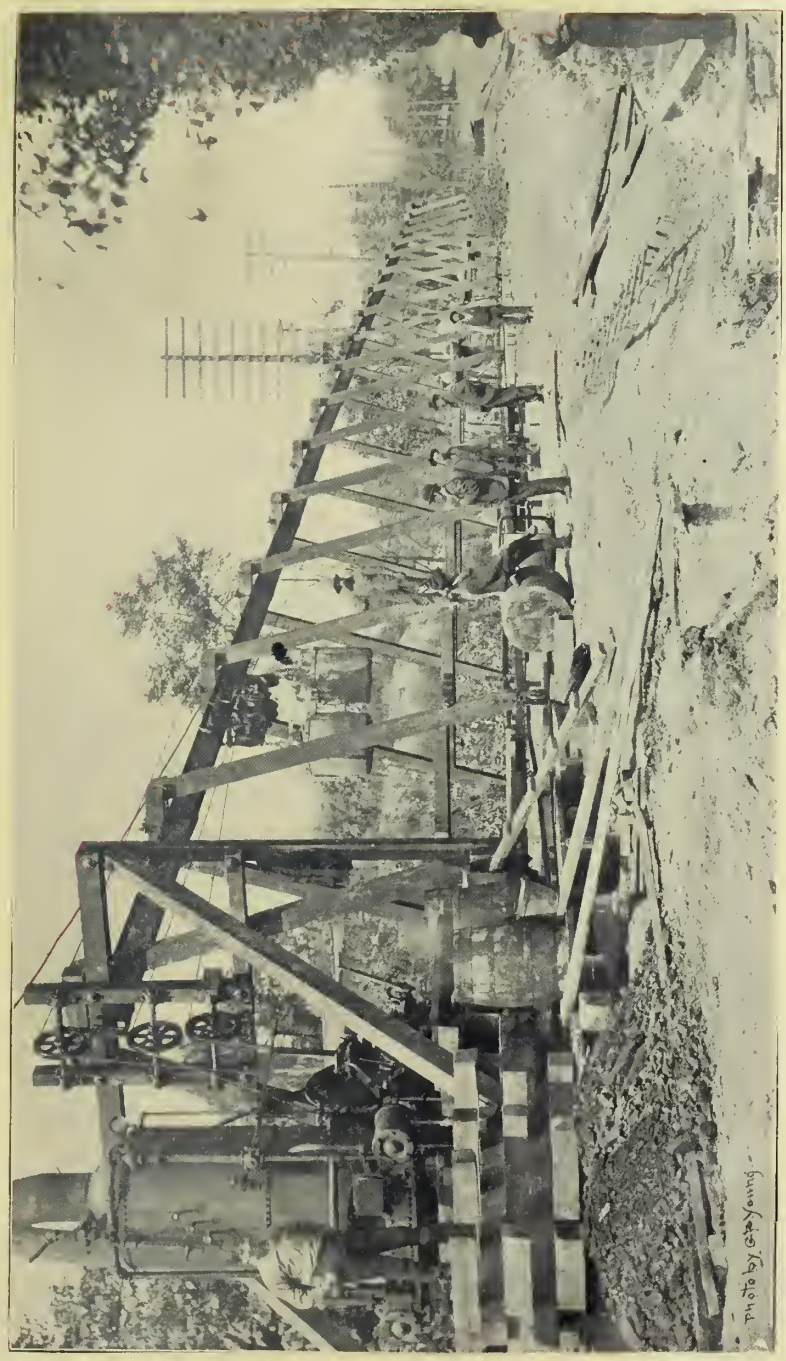


Fig. 29.

them the necessary distance along the trench and dumping the material wherever back filling is needed. To obtain the greatest efficiency of the machine the number of men casting into each bucket should be just sufficient to fill it during the time occupied in removing, emptying, and returning a set of buckets. These buckets are constructed of flange steel, with double bottoms, and are so balanced that they are top-heavy when full, and bottom-heavy when empty, thus making them self-dumping and self righting. The automatic catches are on the outside of the bucket.

This method of trench excavation is well adapted for city work where all possible obstructions to traffic must be avoided. There is no material deposited along side of the trench and one side of the street can be kept clear for traffic during construction. Fig. 3 0 shows a Carson machine in operation beside a street car line, and cars are able to run in both directions during construction.

Mr. A. W. Byrne states that in completing one 4,000-foot section of the Metropolitan sewer system, at Boston, he used the following force:

1 Engineman	$ 3.00
1 Lockman	2.00
1 Dumper	1.50
8 Shovels at $1.75	14.00
2 Bracers at $2.50	5.00
2 Tenders at $2.00	4.00
2 Plank drivers at $2.00	8.00
2 Men cutting down planks at $2.00	4.00
8 Men pulling planks, etc., at $1.75	14.00
Total	$55.50

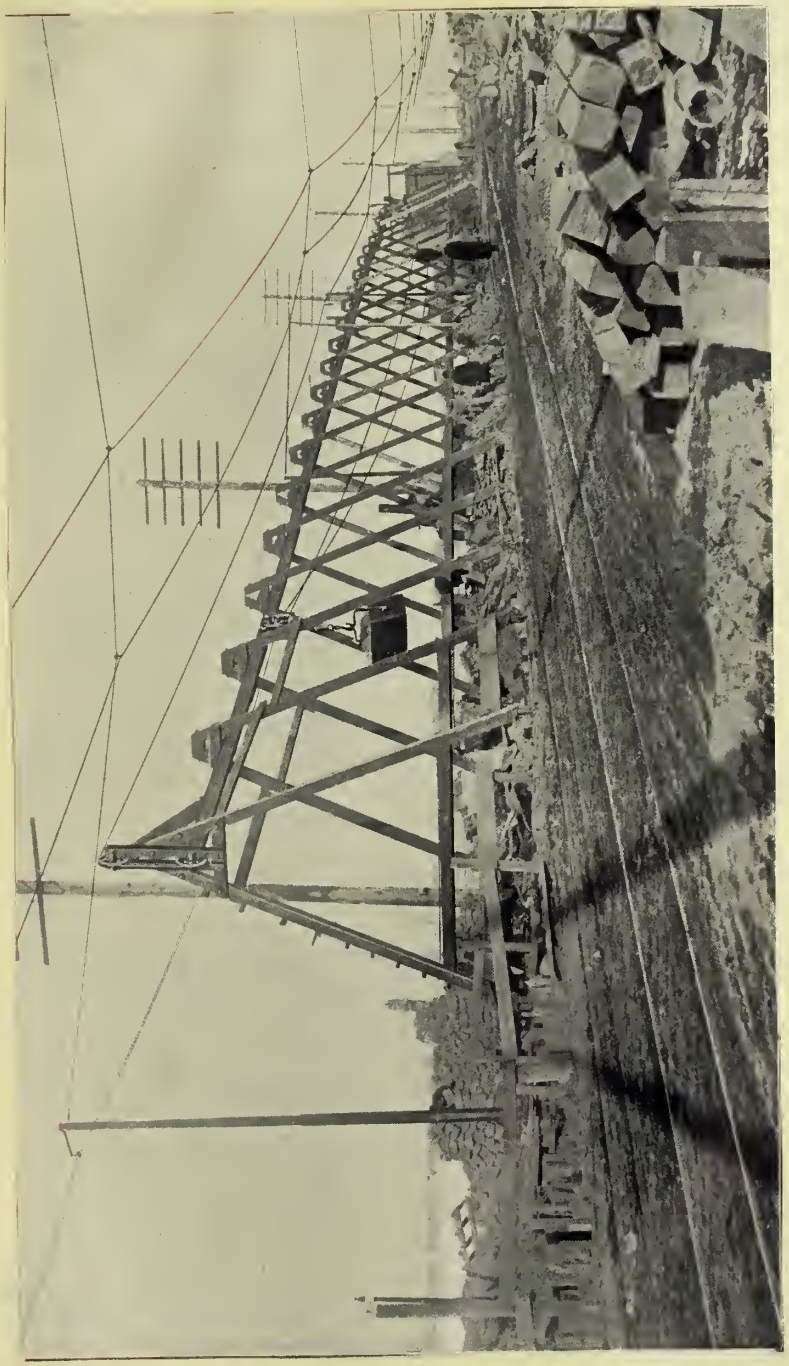


Fig. 30

This force working in a trench 9 feet wide and 20 to 30 feet deep averaged 64 lineal feet per week in " boiling sand", the pressure of which would break 6 by 8-inch stringers 2-1/2 feet apart; and 192 feet per week in gravel and coarse sand, which is equivalent to 70 to 110 cubic yards per day in running sand, and 200 cubic yards in good ground, at a cost ranging from 80 to 25 cents per cubic yard. A steam pump running at a cost of $10 per day was also required, and about 1/2 ton of coal was used by the trench machine. The work mentioned was done after the trench machine was set up, and the gang well organized.

(2) POTTER

The Potter Hoister and Conveyor is somewhat similar to the Carson machine, but instead of carrying the buckets along on a trolley, as in the latter, the buckets are raised and held by clutches on a bucket car that travels along the top of the trestle.

Fig. 31 shows the general construction of the bucket car and its machanism. The trestle is constructed of steel shapes, and is compesed of 17 sections, each 16 feet lang. The span of the machine is 10-1/2 feet and the height about 7 feet. The upper horizontal frame of the car carries three cross shafts. The middle shaft carries a brake drum, the bull wheel for the traveling rope, and two drums for the separate hoisting ropes. Each of the other shafts carries a grooved wheel for a hoisting rope, and a pulley at each end of the frame supports the traveling rope. This is a steel cable, which starts from the upper drum of the hoisting engine, passes along the trestle and over the traveler, around a tail-block pulley at the rear end of the trestle, and returns again to the traveler and passes around the bull wheel, to which it is attached. The other cable starts from the lower drum of the engine, and goes directly to a ring in the front frame of the traveler. This latter cable holds the traveler stationary while the buckets are being raised or lowered, and pulls it forward again after the buckets have been dumped.

The buckets are raised and lowered by winding the main cable on the bull wheel, which , being attached to the same shaft as the drum, aauses the bucket cables to wind or unwind on the drums. At one end of the trestle is located the hoisting engine

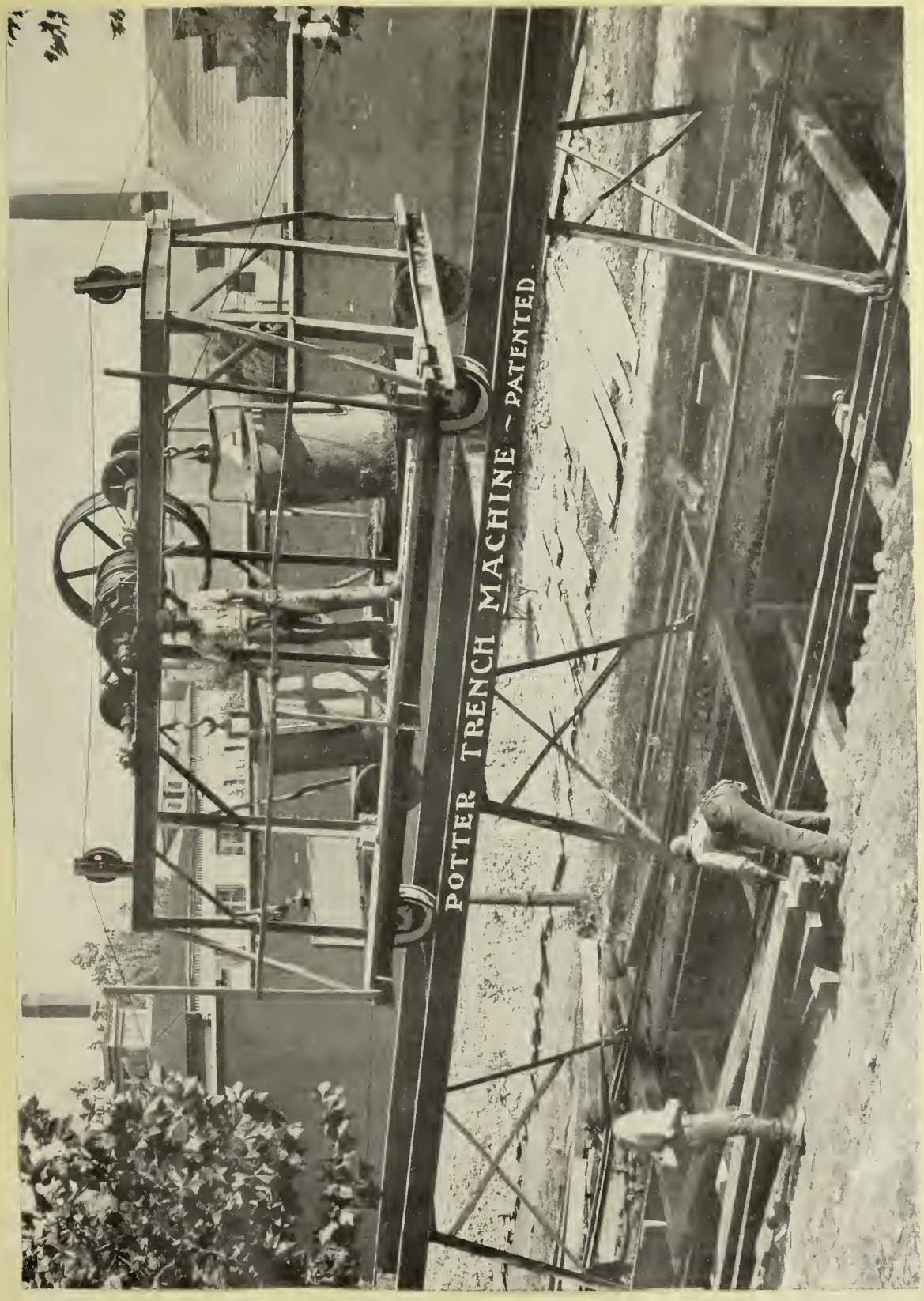


Fig. 31.

that furnishes the power to run the bucket car and buckets. This engine is operated by an enginman in obedience to signals given by the man on the traveler. This engine also serves to pull the whole machine forward as the work progresses.

The conveying car hoists and carries two buckets at a time; these buckets are made of steel and vary from 1/3 to 1 cubic yard in capacity. The car is able to make a round trip in one minute, that is, it can lower and hoist two buckets and run the car back and forth the length of the trestle.

A Potter Trench Machine was used in excavating a trench for a sewer at South Bend, Ind., during the year 1906. The trench was 18 feet deep and 8 feet wide. With wages at 18-1/2 cents per hour for the engineer on the machine, the cost of excavating per cubic yard was given as follows:

Pipe for sub-drain	$0.047
Labor laying this pipe	0.050
Pumping water	0.065
Excavation and back filling	0.400
Sheeting and shoring	0.150
Tools and general expenses	0.035
Total	$0.747

This does not include the rent of the machine nor apparently the cost of coal, which items would add nearly 50 per cent to the cost given.

The Potter machine was used for deep trenching on Lawrence Avenue, Chicago, where a sewer was built in 1907. Fig. 32 shows a view of the machine in operation on this job. Laborers were paid at the rate of 34 cents per hour and the engineer on the machine 75 cents per hour. One-half ton of coal was con-

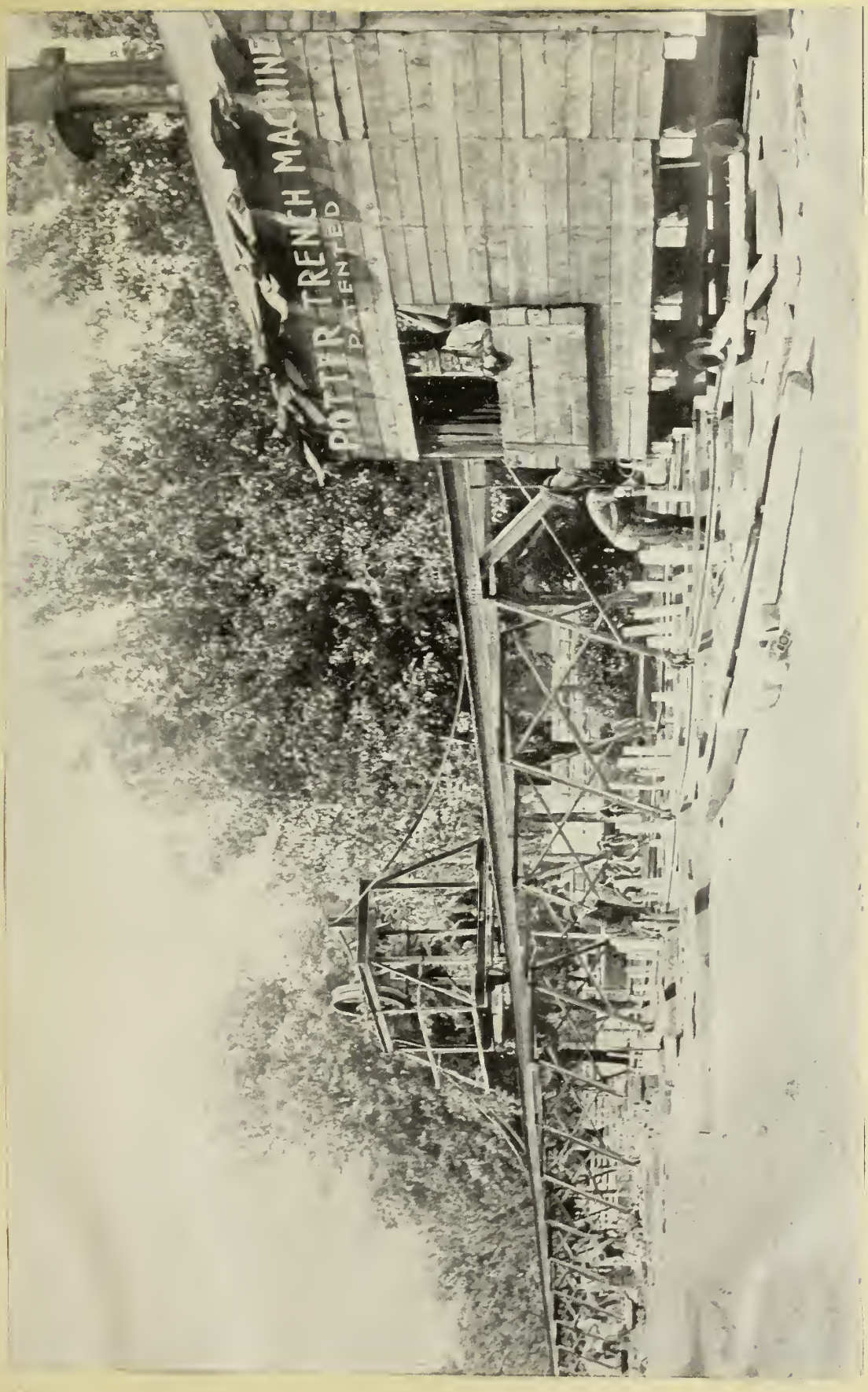


Fig. 32.

sumed each day by the machine and the rent of the machine was given as $4.80 per day. The total daily expense was as follows:

One engineman	$ 6.00
One fireman	2.50
One carriage man	2.50
20 bottom men	55.00
One dump man	2.75
Foreman	3.50
Coal and rent	7.30
Total	$82.80

An average of 175 cubic yards was excavated each 8-hour day, which made the cost about 47 cents per cubic yard, with no allowance for sheeting.

(b) OVERHEAD CABLEWAY

The overhead cableway type of trench machine, in which buckets travel on a trolley along a cable, is especially adapted for city work where all possible obstructions to traffic must be avoided, and especially, where the trench is so wide that a trestle bent cannot well be made to span the trench.

The general method of setting up this type of machine is shown in Figs. 33 and 34. The first shows a view of the construction of the Walworth Run Sewer at Cleveland, Ohio, which was built by Bramley and Gribben. The latter illustration shows the work on the Main Interceptor, Lake Shore Boulevard, Cleveland, Ohio. The machine consists of two A-shaped bents or towers, 20 to 50 feet high, and 200 to 500 feet apart, which support a cable along which the bucket travels. At one end is placed a hoisting engine which raises and transports the buckets. The anchorage for the main cable is made by digging a trench 5 to 6 feet deep and 16 feet long, in which a log 16 or 18 inches in diameter and about 15 feet long is laid, and the cable carried around its center. A short narrow trench leads off from the main trench so as to give a clear way for the cable to pass to the top of the tower. The main trench is filled with stones carefully laid over the log, and on top of the ground over the log is built a pile of stones about 6 feet high. The buckets, which are loaded by hand, are raised and transported back to the completed sewer, and the material dumped. If there is too much earth for the back fill, the excess can be dumped into wagons and hauled away. This handling of buckets loaded by hand is evidently limited to a large extent by the number of men shoveling in the trench. As a rule

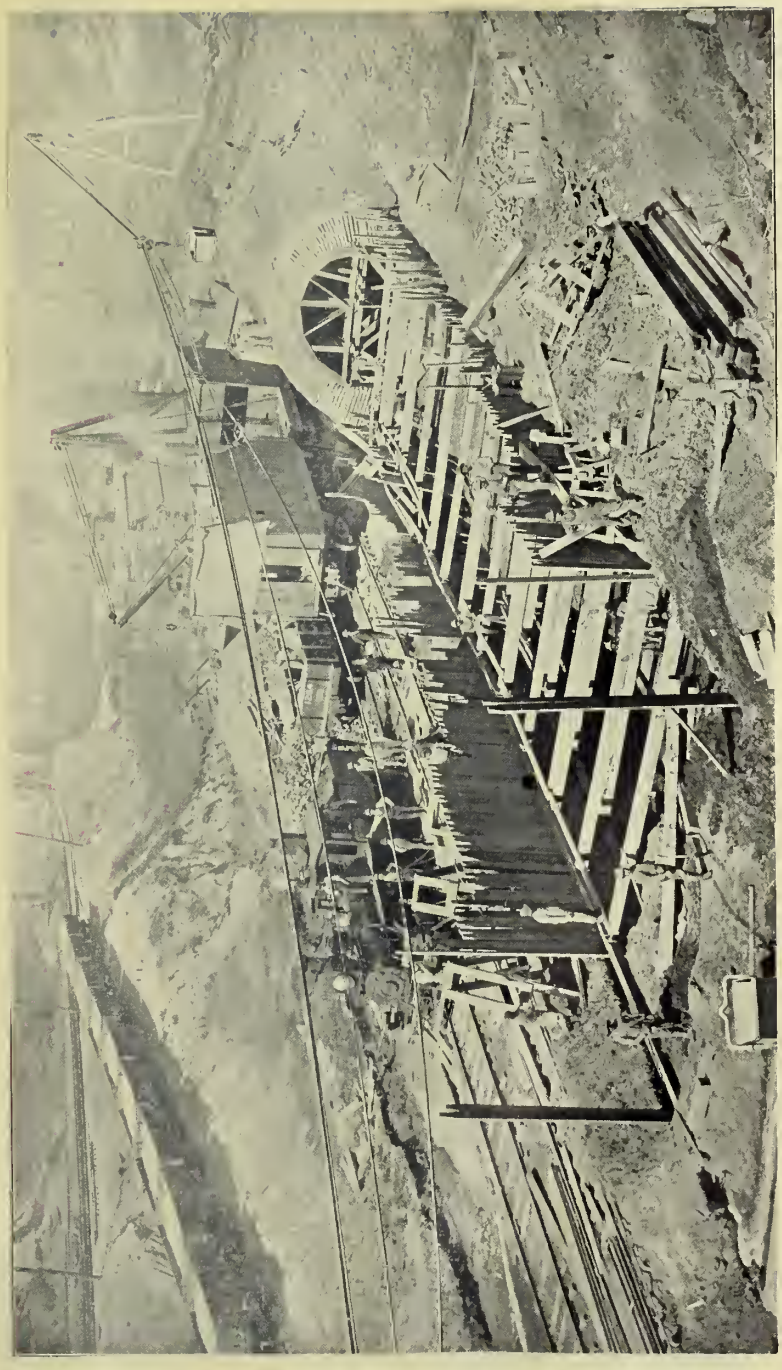


Fig. 33.

Fig. 34.

one or two buckets are in the trench being filled while another is discharging its load.

A cableway may be used to advantage in pulling sheet planking, and one 2 by 10-inch plank buried 16 feet in the earth can be pulled in one minute, thus making the cost of timber removal merely nominal. In pulling the plank a piece of 1 by 3 inch iron, bent into a V-shape and with a ring welded to one leg of the V, is used.

The cost of moving the engine, towers and cables, and setting them up again must be considered when choosing the cableway for trench excavation.

In Boston, parallel with a railroad track, a trench 14 feet wide by 18 feet deep was dug in earth slightly more compact than " average". A cableway with towers 400 feet apart was used, and it delivered the buckets to a chute that discharged into railroad cars alongside. The record of cost was as follows: 30 men loading buckets, 1 signalman, 1 man hooking buckets to cable's trolley, 1 man dumping buckets, 4 men driving sheet plank and bracing, 5 men spreading earth in cars and moving cars, 1 engineman, 1 fireman, 1 water boy, and 1 foreman, making a total of 46 men. The output was 266 buckets in 10 hours, each bucket holding 1-1/3 cubic yards of loose earth, which amounted to about 1 cubic yard measured in cut. The wages and coal amounted to $76.00 a day. Hence, not including the cost of timber sheeting, nor the hauling and unloading of cars, the cost of excavation was about $.30 per cubic yard. When the bucket was traveling 360 feet from pit to dump, the average time required for each round trip was 2-1/3 minutes.

Mr. Frank P. Davis, C.E., gives the following data for a sewer in Washington D.C.: width of trench, 18 feet; depth at which caoleway began work, 15 feet; distance of travel of 1 cubic yard bucket, 150 feet; number of trips per hour, 35; hours per day, 8; material, cemented gravel. The cost was as follows:

Engineman	$ 2.00
Fireman	1.25
Signalman	1.00
2 Dumps at $1.00	2.00
Coal, oil, and waste	1.50
Interest and maintenance(estimated)	7.00
30 men picking and shoveling	30.00
Total for 280 cubic yards	$44.75

The cost of picking, shoveling, hoisting 15 feet, and conveying 150 feet to wagons, was 16 cents per cubic yard. (Note that the wages were very low.)

(c) DERRICK

In trench excavation work it is frequently necessary to use a derrick for handling the earth. Either wooden "skips" or iron buckets are filled with earth by shovelers, and a man-operated, horse-operated, or power-operated derrick is used to lift the buckets out of the way. Work of this character is always expensive; for only a few shovelers can be worked in the pit, and as a consequence the derrick is never worked to its capacity.

Where there are trees or telephone poles to anchor to, a guy-derrick is to be preferred, for there are not several tons of stone to be handled, as on a stiff-leg derrick which must be weighted down. Moreover a guy-derrick is quite easily shifted a long distance, even while standing.

Fig. 35 shows the general method of using a horse-operated derrick in trench excavation. The material is deposited on the waste bank at one side of the ditch; if there is an excess of material, it can be hauled away by loading into wagons.

For a comparatively small job, the contractor can readily make a traveling derrick by mounting a small derrick and double-drum hoisting engine on a platform car. Buckets or skips loaded by hand are used after the trench gets to be over 5 feet deep. The derrick raises these buckets, swings them to one side, and dumps the material along side the trench; or they can be dumped into one-horse dump carts, the material being thus hauled back a few hundred feet and used for back fill, or the excess hauled away and wasted. The derrick is moved forward as the work progresses by hitching a rope to a tree or other anchorage ahead and passing it around the winch head of the engine.

Fig. 30.

Mr. D.J. Shafer used a horse-operated derrick in excavating a trench for a sewer at Big Rapids, Mich. The trench was 4 feet wide, with an average depth of about 15 feet. About 5 feet was removed from the top with a slush scraper, leaving an average of 10 feet to be taken out in buckets, two being used with a capacity of 4 1/2 cubic feet each. Working in this manner an average was made of 50 lineal feet of sewer per day, or about 500 bucket loads. The actual performance of the outfit while at work was usually a little better than 60 buckets, or 10 cubic yards, per hour.

The moving of the derrick was accomplished in seven minutes, and three moves were usually made in a day.

CONCLUSIONS

As a general statement it may be said that it pays to use machinery in excavating where the trench is over 1000 feet long and more than 4 feet deep or wide. The question of what type of machine to use has already been discussed. The advantages obtained in using machinery are: greater amount of material excavated with a given number of men; less obstruction to street traffic; less danger of the caving of the banks from the weight of earth piled upon them; faster work; and a more efficient organization as a whole. Asthe depth of the trench increases, each of thes advantages likewise become greater.

With machinery the cost of handling material increases but little with the depth, whereas it increases very rapidly where excavating in deep trenches is done by hand. In using the latter method for deep trenching, a system of "staging" must be installe and the excavated material is handled several times before reaching the surface.

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